ON THE CHOICE OF THE HIGH-SPEED DIESEL ENGINE FOR THE PROPULSION OF SMALL VESSELS

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ABSTRACT

High speed diesel engines are largely used in the propulsion of small vessels, working boats, yachts where one or more engines are installed on board to supply power ranging from a few to over 1000 kW.

This paper presents some simple expressions obtained analytically by statistical methods which would easily calculate the weight and dimensions of such engines by first approximation. Thus, these equations may help, in the preliminary stage of design of a vessel, when the development of the calculation requires knowing the weight and dimensions of the engine to be installed on board.

Moreover, this paper presents, by histograms, the distributions of the main characteristics of the engines under investigation.

INTRODUCTION

Since its appearance on the industrial scene at the end of the last century, the diesel engine has developed technologically so as to be largely employed in fields where its characteristics were particularly required.

In a wide range of applications where its use had been excluded at first, the diesel engine has gained, in some cases, a position of monopoly, nowadays. It would be enough to mention car and heavy traction, the extensive naval applications, the application in the electric energy production etc.

In the naval field, the diesel engine applies widely to all types of recent vessels, from the large to the medium size ones, to yachts and working boats, etc. Particularly, for the small ratings, the diesel wins the market from the gasoline engine whose application in this field is decreasing in time because of the costs and the relative unsafety of gasoline.

The marine diesel engine is variously applied: as a prime mover for the propulsion of fishing boats, pilot boats, yachts, tugs, etc; as an auxiliary engine for the production of the electric energy on board of medium and large size ships.

OBSERVATIONS ON THE CHOICE OF THE ENGINE FOR SMALL VESSELS

The choice of the engine to be installed on board of small vessels can be rather puzzling because of a number of concurring circumstances: first of all, when the size of the vessel decreases, the percentage of the space occupied by the engine increases in comparison to the space available on board.

The same problem arises with the weight: the smaller is the displacement of a ship, the higher is the share of weight of the engine.

Table 1 shows some reference values of the ratio W/Δ (in percentage) as a function of Δ . W is the weight of the propulsion plant and Δ is the total displacement of the vessel.

Δ (t)	W / Δ (%)
>100000	1
10000 ÷ 100000	1 ÷ 5
1000 ÷ 10000	3 ÷ 10
100 ÷ 1000	5 ÷ 15
< 100	10 ÷ 50

Tab. 1

These data further confirm the need to optimize the choice of the engine as regards its weight and dimensions, at the decreasing of the size of the vessel.

No evaluating procedures on these dimensions are available to the designer in the choice of the engine; the available data, on the other hand, are neither systematically presented nor sufficiently analyzed.

This paper has, therefore, a double purpose:

- to present statistics, as exhaustive as possible, on the data pertaining the high-speed diesel production;

- to present some analytical expressions which would be useful for the evaluation of the weight and dimensions of the engine in the phase of preliminary project.

The units of measure and the symbology in this text are given in the appendix.

THE ANALYZED SAMPLE

This analysis is based on an initial sample of over 1000 high-speed diesel engines whose characteristics have been taken either from promotional brochures (required from each manufacturer, on the occasion) or from specialized periodicals [1].

The elaborated data generally relate to units equipped with raw-fresh water heat exchanger, alternator, exhaust manifold, starter, filters, pumps for the lubricating and cooling circuits, flywheel (with its housing, if any), monitoring instruments (thermostats, pressoswitches, alarms, etc.). They refer to the "dry" engine, i.e. with no fluid in the lubricating and cooling circuits.

Though the initial sample was rather large, the processing included only part of it. Various reasons suggested excluding several units:

- engines whose data did not always result homogeneous and complete, thus useful for the statistic investigation;

- engines whose power exceeds 300 kW and those (like the Vee cylinders engines) whose typology was insufficiently represented to constitute a statistically meaningful subsample;

- engines whose technology appeared too far from the recent producing trends or mostly unsuitable for naval application.

The engines have been further selected in order to be gathered in groups which could be congruent to the analysis of each quantity, in turns. Eventually, this selective process has given four distinct samples of engines that have been used as database to define the equations calculating the four examined quantities.

The distributions of the main characteristics of the examined engines are represented by histograms in figures 1 to 13.

USEFUL EXPRESSIONS FOR DETERMINING WEIGHT AND DIMENSIONS

The analysis was carried out by means of the linear regression which provided a simple equation for each one of the following quantities: length, breadth, height and weight.

The first step consisted in determining the other characteristics of the engines which could influence the determination of the quantities under process. The following five characteristics appear to be meaningful for each of the four abovementioned variables: power, rpm, bore, stroke, number of cylinders.

Indicating by V the dependent variable in exam, the generic regression equation results as follows:

$$V = \sum_{i=1}^{r} c_i \; 10^{E_i} \; X^{p_i} \; Y^{n_i} \; T^{d_i} \; U^{s_i} \; W^{z_i} \tag{1}$$

where:

$X = P$

$Y = N/1000$

$T = D/10$

$U = S/10$

$W = Z$

r = number of terms

$p_i + n_i + d_i + s_i + z_i \leq 3 \qquad i \leq r$

The exponents p_i , n_i , d_i , s_i , z_i are given in tables 2 to 5.

Note that, in the equation of the height, the term related to the power does not appear because the regression analysis got an acceptable value of the mean error already before processing the terms inclusive of the power.

On trying to homogenize the sets of engines, one of the main difficulties was due to the presence of a gearbox. In fact, for a high propulsion efficiency, the propeller coupled with a high speed engine requires an rpm largely lower then the one of the engine. This leads to a virtually general need to resort either to a gearbox or, even more frequently, to a reverter gearbox by which the propeller can reverse its direction of rotation.

The weight and length of the engine-gearbox unit are highly influenced by the dimensions of the gearbox alone; in elaborating the expressions of these two quantities one cannot neglect the fact that such a device be there or not.

Anyway, the material available to the authors has not always indicated the presence or simply the type of gearbox installed; thus the engines lacking such news have not been taken into account in processing the expressions of weight and length.

As regards the values of the power, it is worth pointing out that they almost always refer to the indication of "continuous power" according to the standard ISO 3046. Sometimes, however, manufacturers, rather than refer to ISO 3046, list some values of the power related to various operating conditions. In these cases, it was decided to choose the value considered closer to the one specified as "continuous power" in the abovementioned standard.

Further details on the definition of the processed samples will be given in the paragraphs dedicated to each single quantity.

Length

In evaluating the length of the engines to be analyzed, the lack of specifications for the gearboxes has caused more serious difficulties than for the other quantities in exam. This is due to the fact that the length of different types of gearboxes, though their reduction ratio may be equal, may vary greatly, since the disposition of the inner parts largely bears on the dimensions of the gearbox itself.

Consequently, when the length datum was not surely referring to the engine-gearbox unit, it was deemed preferable to exclude the engine from the elaboration so as to prevent a loss of meaning of the analyzed sample. This is the reason for the reduced number of samples in determining the regression equation of the length.

Table 2 shows the regression equation (1) exponents and coefficients relating to the length together with the number of samples used, the standard percentage error and the correlation coefficient. Figure 14 shows, by histograms, the distribution of the percentage error found, together with the related Gauss curve.

Breadth

The breadth distribution appears rather homogeneous and depending upon both the typology of the engine and the displacement of some of its parts.

It has been noticed, for instance, that in the engines conceived for marine use from the start (and to be used, therefore, coupled with a gearbox) the superchargers are set on the back (opposite to the place where the flywheel is) so as to limit the overall width.

On the other hand, in the engines intended also for other applications (where there is no particular need of limiting the width in comparison to the other dimensions) usually the turbochargers are set on the side of the cylinders; as a consequence, the overall breadth is larger.

Table 3 and figure 15 show the sample characteristics and the regression parameters:

Height

This quantity has not caused any major problem in composing the sample. Anyway, it was noticed that the aftercooled engines are, as a mean, higher then the non-aftercooled ones because the aftercooler is generally set in the upper side of the engine.

Table 4 and figure 16 show the regression characteristics for the height.

Weight

In defining the sample to be analyzed to elaborate the weight expression, the engines lacking sufficient specifications created the same sort of difficulties already described for the length, although the group of examined gearboxes resulted to be more homogeneous for the weight that it had been for the length. In other words, for the engines lacking the dimensions of the propeller plus gearbox, it was easier to determine the weight then the length. Thus the sample for the weight is larger then the one for the length regression.

The definition of the weight of the engine-gearbox set for those engines whose producers recommended a particular gearbox, was obtained simply by summing up the weight of the recommended gearbox with that of the engine. When the recommended gearboxes are more than one, we chose the one whose reduction ratio was closer to four.

Table 5 and figure 17 show the characteristics of the examined sample and the regression carried out.

CONCLUSIONS

In the design of a small vessel, the evaluation of the engine weight and dimensions contribute in a conclusive way to the definition of the vessel general characteristics (stability, running trim, distribution of spaces on board, etc.).

The availability of simple analytical tools may greatly help the first phase of project, when the inevitable initial indefiniteness may be overcome by some reference values on which to develop a preliminary project.

Therefore, some regression expressions have been elaborated which, starting from the characteristic values of the high speed diesel engines, help determining the probable values of length, breadth, height and weight.

Moreover, we presented statistics on a remarkable sample of engines which can help defining the characteristics of the engine to be installed on board.

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[1] Diesel & Gas Turbine Worldwide Catalog; Brookfield, USA, Diesel & Gas Turbine Publications, 1989

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APPENDIX

P	- Power	[kW]
P_s	- Specific power	[kW/dm²]
N	- RPM	
D	- Bore	[mm]
S	- Stroke	[mm]
DS	- Displacement	[litres]
Z	- Number of cylinders	
L	- Length	[mm]
B	- Breadth	[mm]
H	- Height	[mm]
W	- Weight	[kg]

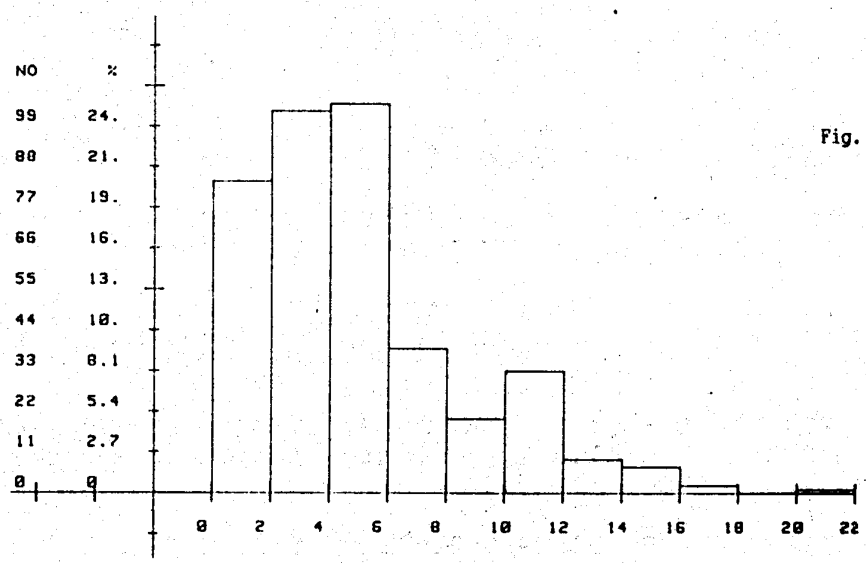

Fig. 1 - Displacement

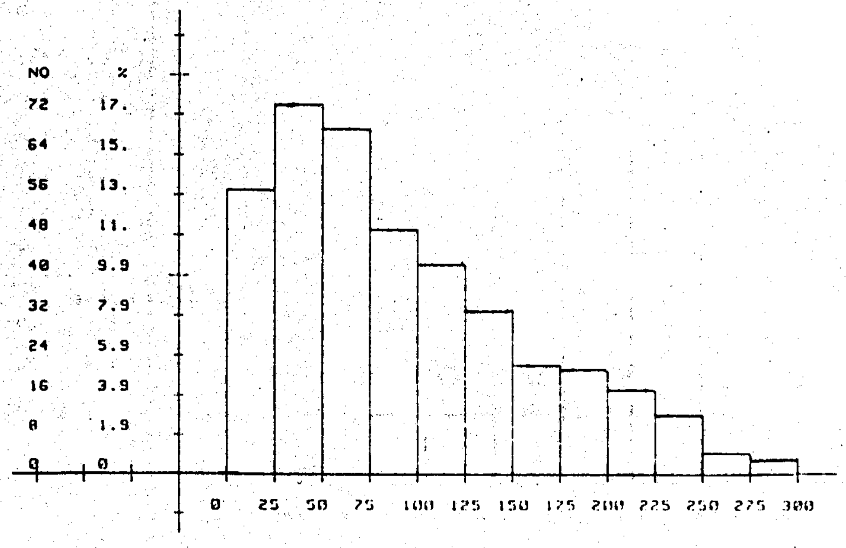

Fig. 2 - Power

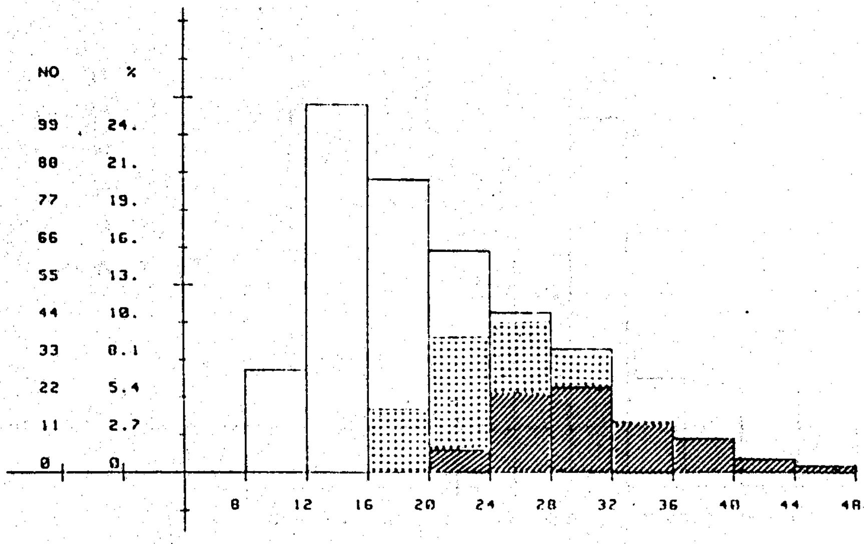

Fig. 3 - Specific power

supercharged

supercharged and intercooled

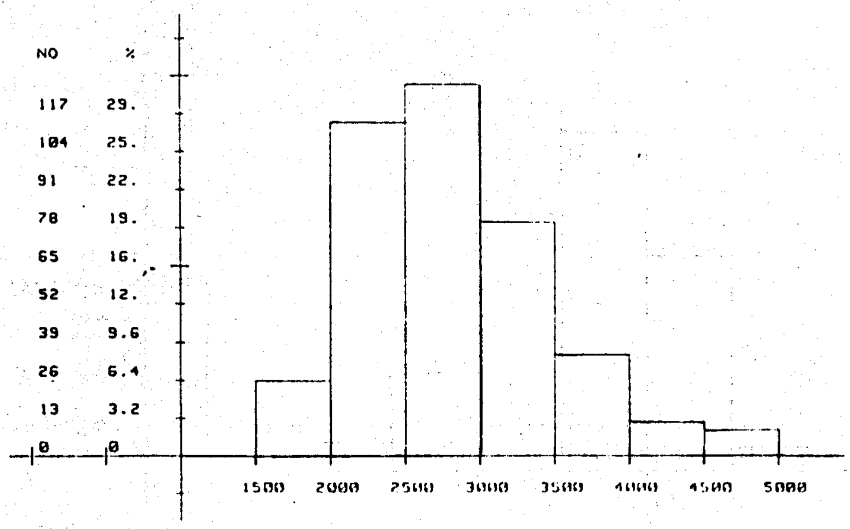

Fig. 4 - RPM

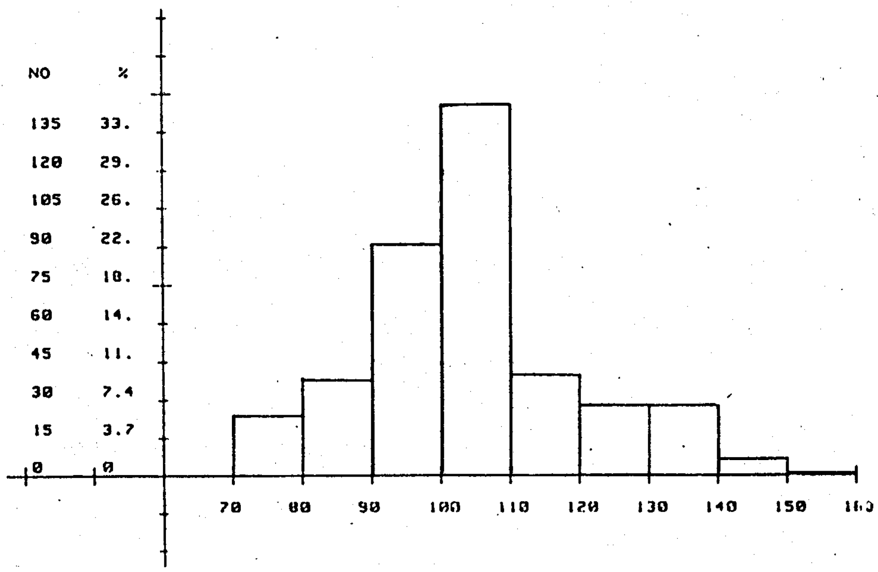

Fig. 5 - Bore

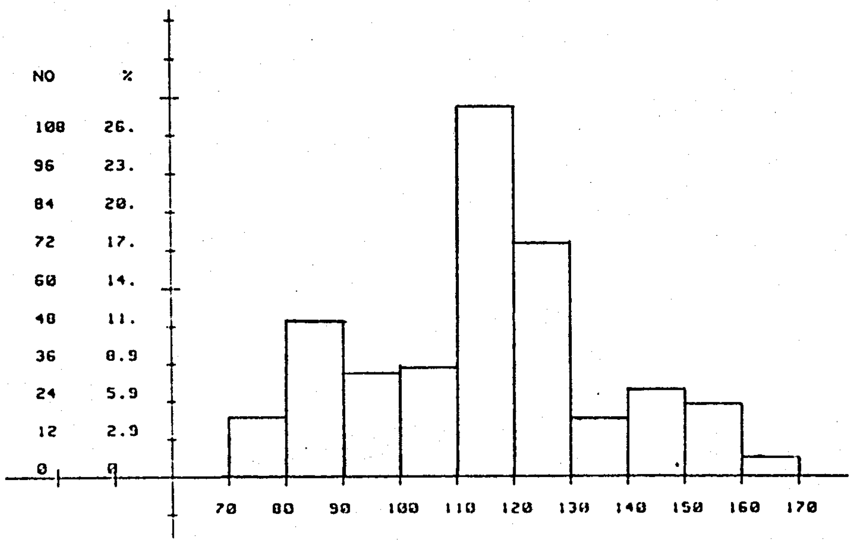

Fig. 6 - Stroke

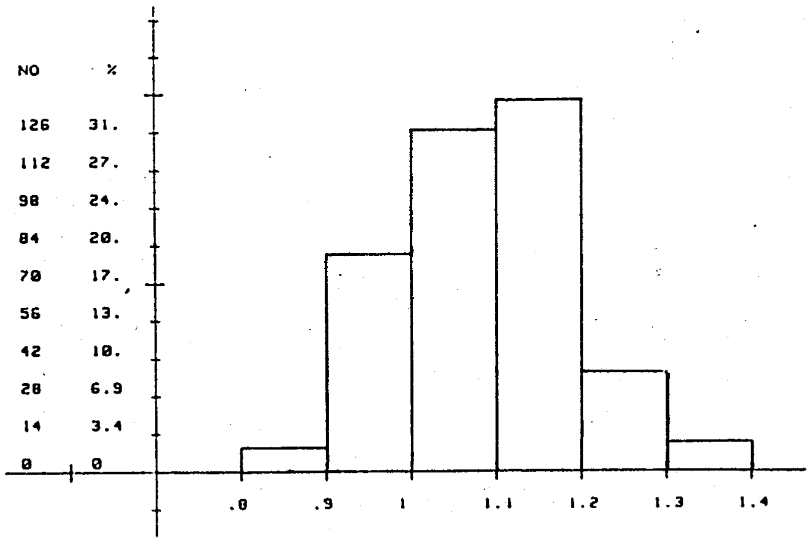

Fig. 7 - Bore / stroke ratio

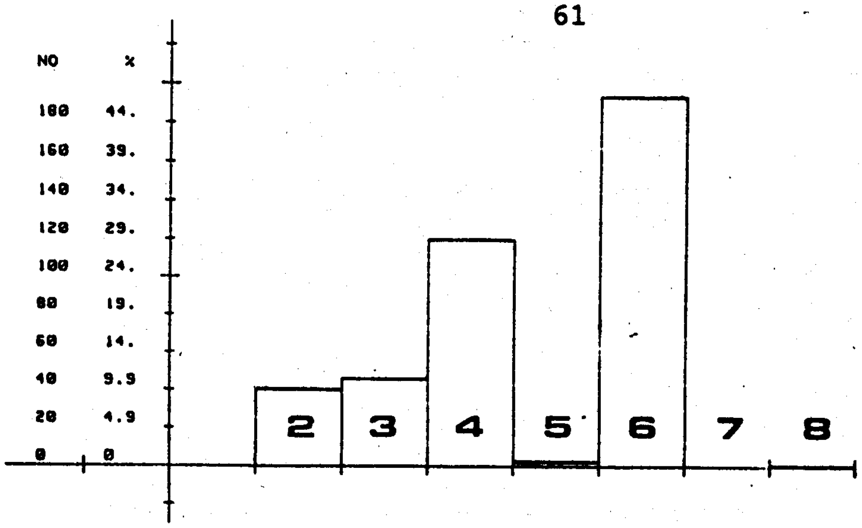

Fig. 8 - Number of cylinders

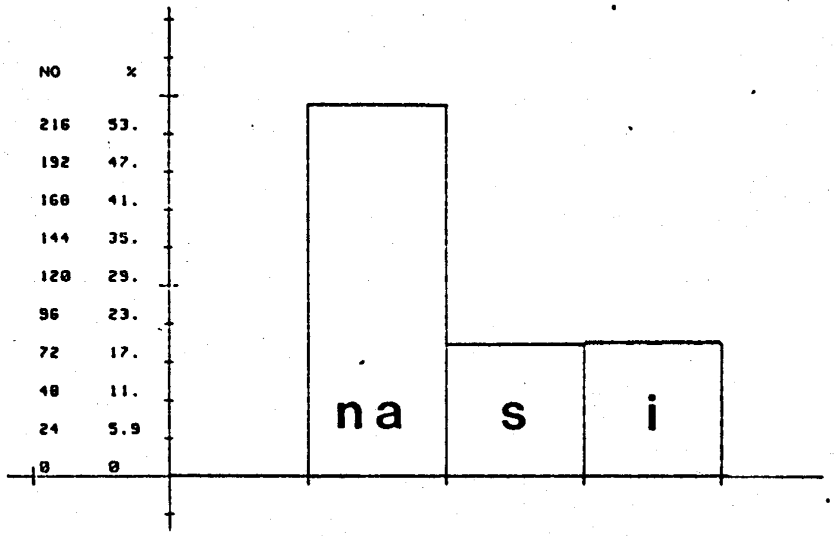

Fig. 9 - Supercharging

na naturally aspirated

s supercharged

i supercharged and intercooled

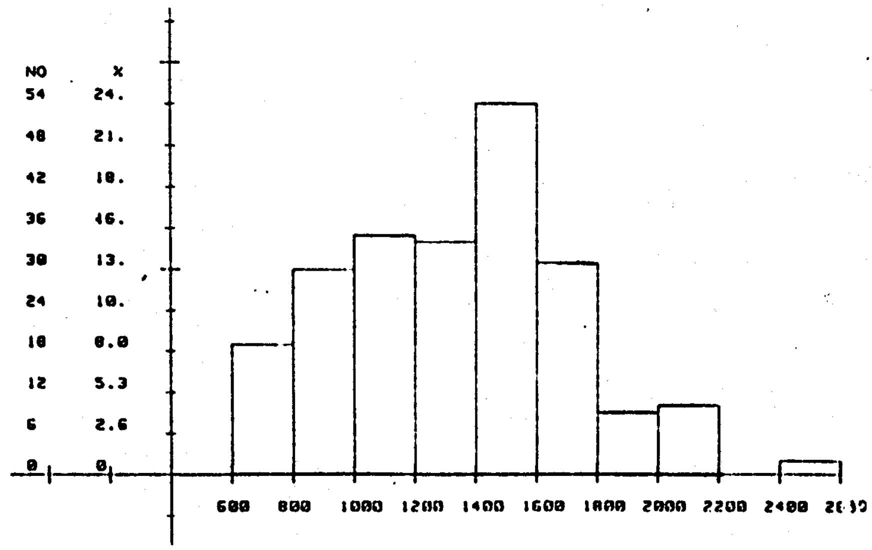

Fig. 10 - Length

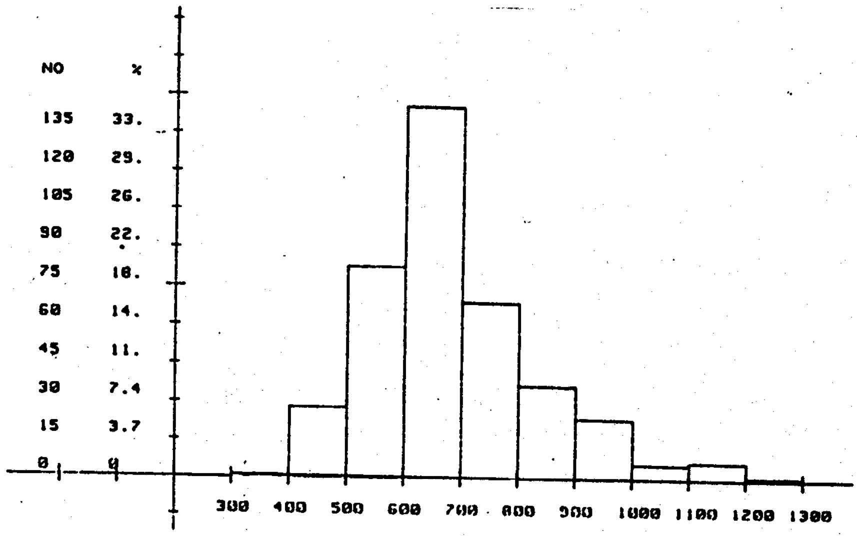

Fig. 11 - Breadth

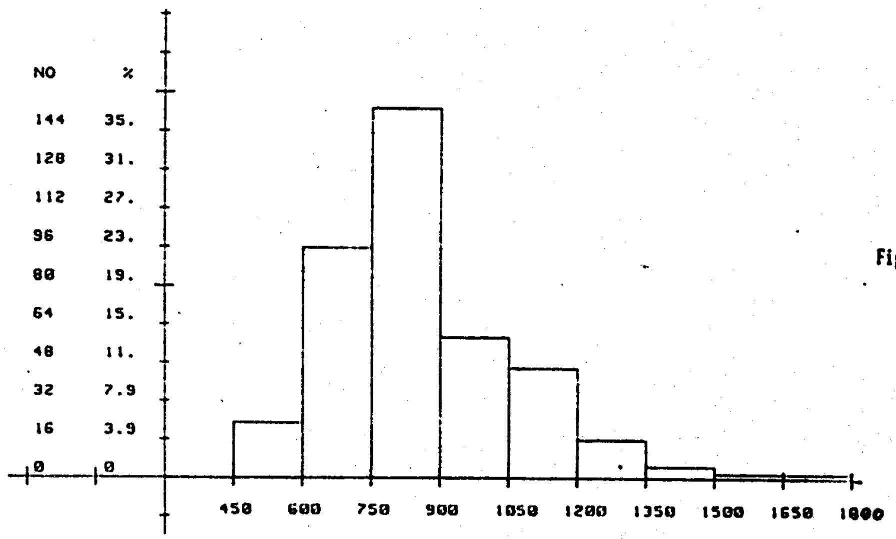

Fig. 12 - Height

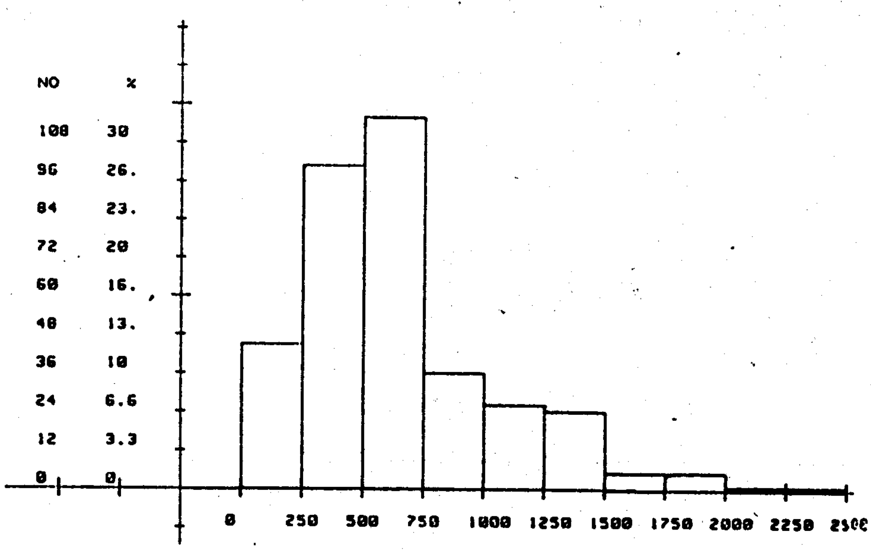

Fig. 13 - Weight

LENGTH						
CORRELATION		.714	-.639	.822	.847	.746
C_i	E_i	p_i	n_i	d_i	s_i	z_i
2.23458	3	0	0	0	0	0
-8.57307	2	0	1	0	0	0
1.13985	1	0	3	0	0	0
6.16632	0	0	2	1	0	0
5.94034	0	0	1	1	0	1
-5.39661	-1	1	2	0	0	0
3.08194	-1	1	0	2	0	0
1.17747	-1	1	1	0	1	0
-5.80739	-1	1	0	1	1	0
2.66186	-1	1	0	0	2	0
NUMEROSITY OF SAMPLE				224		
MEAN ERROR				7.57		

Tab. 2

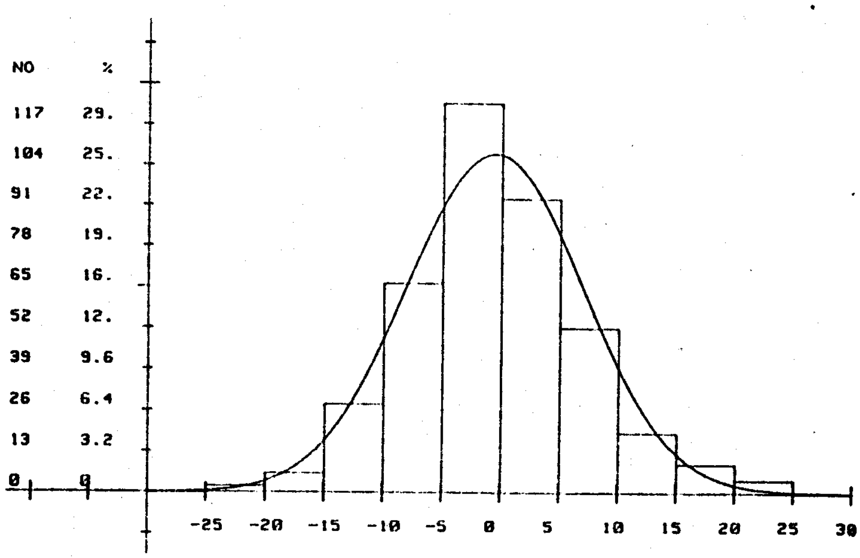

Fig. 14

BREADTH						
CORRELATION		.758	-.526	.752	.746	.619
C_i	E_i	p_i	n_i	d_i	s_i	z_i
7.41555	2	0	0	0	0	0
-1.36478	2	0	1	0	0	0
1.05150	-1	0	0	2	1	0
4.74949	0	0	2	0	0	1
7.57304	-1	1	0	0	0	0
-2.56357	-2	1	0	0	2	0
1.23979	-1	1	0	0	1	1
-2.16410	-1	1	0	0	0	2
3.36939	-3	2	0	0	0	1
-4.87688	-5	3	0	0	0	0
NUMEROSITY OF SAMPLE				409		
MEAN ERROR				8.62		

Tab. 3

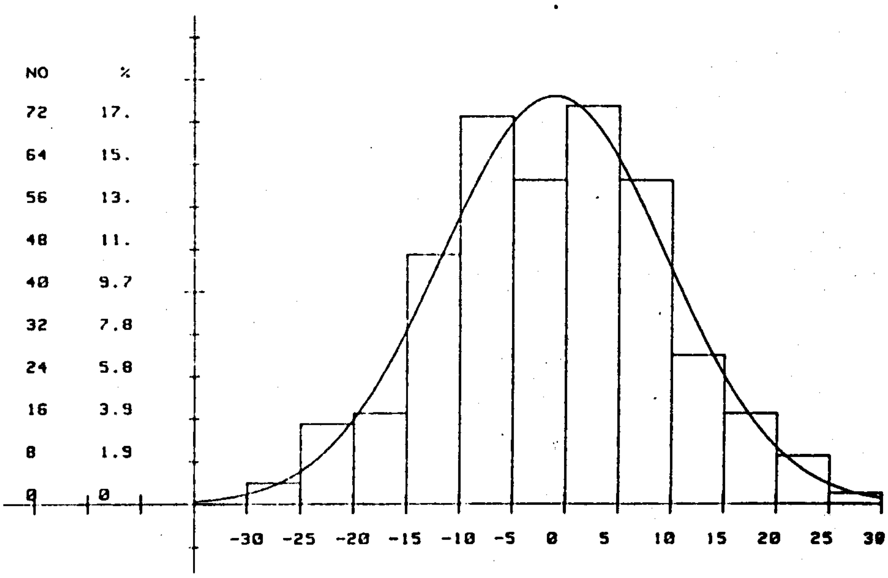

Fig. 15

HEIGHT					
CORRELATION		-.679	.861	.868	.593
C_i	E_i	n_i	b_i	s_i	z_i
-6.13261	2	0	0	0	0
1.69143	1	1	1	0	0
7.69045	-1	0	3	0	0
2.19431	2	0	0	1	0
-1.65943	1	0	1	1	0
-3.03223	0	1	1	1	0
2.54913	0	0	0	2.	0
2.18565	0	1	1	0	1
-6.13658	-1	0	0	0	3
NUMEROSITY OF SAMPLE			409		
MEAN ERROR			5.84		

Tab. 4

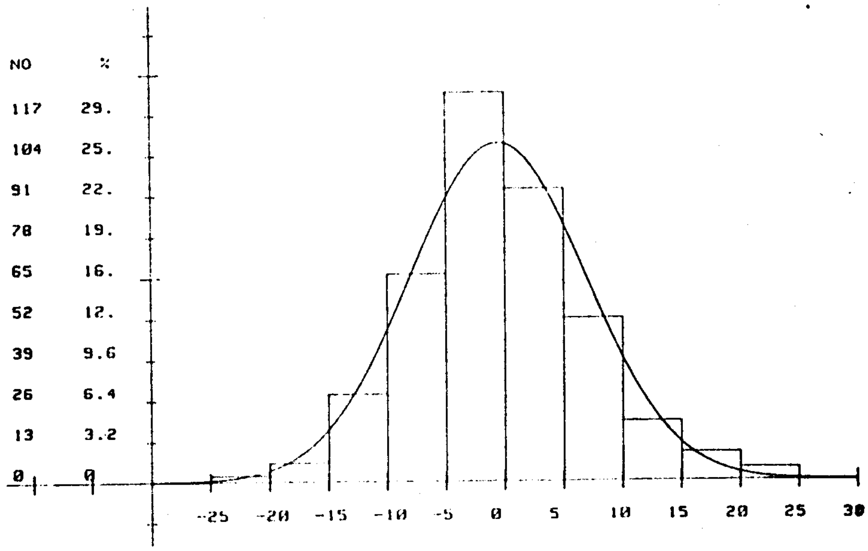

Fig. 16

WEIGHT						
CORRELATION		.809	-.698	.902	.877	.579
C_i	E_i	p_i	n_i	d_i	s_i	z_i
1.11534	2	0	0	0	0	0
-9.60176	0	0	3	0	0	0
4.80311	0	0	2	1	0	0
6.76565	0	0	2	0	1	0
-4.55368	0	0	1	1	1	0
5.53770	-1	0	0	2	1	0
4.71753	-2	0	0	0	3	0
-1.52065	0	0	1	0	1	1
7.77665	-1	0	0	1	1	1
1.72388	0	1	0	0	0	0
-1.22539	-5	3	0	0	0	0
NUMEROSITY OF SAMPLE				360		
MEAN ERROR				8.02		

Tab. 5

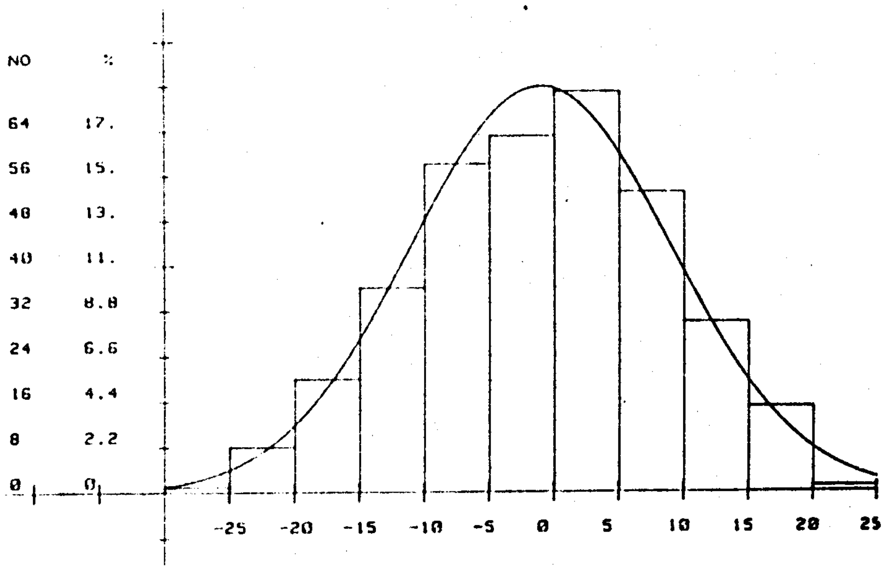

Fig. 17